Liver and heart failure: an ultrasound relationship

Article *in* Journal of Basic and Clinical Physiology and Pharmacology · September 2022

DOI: 10.1515/jbcpp-2022-0211

10 authors, including:

Anna Lombardi
Azienda Sanitaria Locale Napoli 3 Sud
16 PUBLICATIONS **29** CITATIONS
SEE PROFILE

Stefano Palermi
University of Naples Federico II
72 PUBLICATIONS **313** CITATIONS
SEE PROFILE

Alessandro Serio
Policlinico Federico II di Napoli
9 PUBLICATIONS **12** CITATIONS
SEE PROFILE

Simona Sperlongano
University of Campania Luigi Vanvitelli
52 PUBLICATIONS **397** CITATIONS
SEE PROFILE

Review

Anna Lombardi*, Michele Gambardella, Stefano Palermi, Francesca Frecentese, Alessandro Serio, Simona Sperlongano, Rita Tavarozzi, Antonello D'andrea, Massimo De Luca and Cecilia Politi

Liver and heart failure: an ultrasound relationship

https://doi.org/10.1515/jbcpp-2022-0211
Received August 6, 2022; accepted August 22, 2022;
published online September 19, 2022

Abstract: Liver and heart are anatomically and pathophysiologically related. In heart failure (HF) the increased right atrial pressure and volume overload cause histological changes in hepatocytes, leading to a condition known as "congestive hepatopathy" (CH), with consequent variations in liver functioning and ultrasound (US) findings. CH has specifical US findings especially regarding venous vessels aspect, easily detecting by gray-scale study, but many others can be distinguished by Doppler analysis. Usually, hepatic veins look enlarged and hypocollassing, together with signs of portal hypertension (hepatomegaly, ascites, splenomegaly, porto-systemic collaterals). Typically, in CH Doppler findings regard alterations in venous vessel flow and arterial resistance (venous system hyperpulsatility, reduced velocity flow, high resistance index in hepatic arterial Doppler spectrum). Sometimes CH and other primary hepatopathy can coexist, and therefore some of the expected variations may not manifest: it allows suspecting an unknown underlying liver disease. At last, US technologies of more recent applications, even if not routinely used, allow investigating additional aspects such as elastography that detects changes in liver elasticity or contrastographic US, able to show differences in hepatic venous opacification. However, most of these US signs are not pathognomonic, and therefore a multidisciplinary clinical reasoning must not be lacking. The aim of the present review is to easily provide US signs of liver alterations in HF, in particular right heart failure with volume overload, suggesting including liver US in instrumental diagnosis and therapeutic monitoring of HF.

Keywords: congestive hepatopathy; heart failure; liver; ultrasound; volume overload.

***Corresponding author: Anna Lombardi,** Department of Internal Medicine, Veneziale Hospital, ASREM, Isernia, Italy,
phone: 0039-3276539201, E-mail: anna.lombardi.dr@gmail.com.
https://orcid.org/0000-0001-6968-4947
Michele Gambardella, Department of Advanced Biomedical Sciences, University Federico II, Naples, Italy,
E-mail: mic.gambardella@libero.it
Stefano Palermi and Alessandro Serio, Public Health Department, University Federico II, Naples, Italy,
E-mail: stefanopalermi8@gmail.com (S. Palermi),
alessandro.serio.1984@hotmail.com (A. Serio)
Francesca Frecentese, Section of Cardiology, Department of Clinical and Experimental Medicine, University of Messina, Messina, Italy,
E-mail: francesca.frecentese@hotmail.it
Simona Sperlongano, Department of Translational Medical Sciences, University of Campania Luigi Vanvitelli, Naples, Italy,
E-mail: sperlongano.simona@gmail.com
Rita Tavarozzi, Department of Translational Medicine, University of Eastern Piedmont, Novara, Italy, E-mail: ritatavarozzi@hotmail.it
Antonello D'andrea, Unit of Cardiology and Intensive Coronary Care, Umberto I Hospital, Nocera Inferiore, Italy,
E-mail: antonellodandrea@libero.it
Massimo De Luca, Liver Unit, Cardarelli Hospital, Naples, Italy,
E-mail: mar70463f@gmail.com
Cecilia Politi, Department of Internal Medicine, Veneziale Hospital, Isernia, Italy, E-mail: cecilia.politi@asrem.org

Introduction

According to the recent guidelines of the European Society of Cardiology (ESC) [1], heart failure (HF) is defined as a clinical syndrome characterized by typical symptoms and signs caused by a structural and/or functional cardiac abnormalities, resulting in a reduced cardiac output, and/or elevated intracardiac pressures at rest or during stress. Therefore, different clinical manifestations of HF exist, and these depend on hypoperfusion and volume overload in a variable way [2]. Central venous pressure (CVP), invasively measured at the vena cava near the right atrium, is dependent on both right atrial pressure (RAP) and the volume status. Several cardiac diseases (tricuspid regurgitation or stenosis, cardiomyopathies, constrictive pericarditis, cor pulmonale) lead to RAP increase; HF itself, whatever its origin, can result in RAP and volume status elevation [3, 4]. The increased central venous pressure is transmitted to the liver through the inferior vena cava (IVC) and the intrahepatic veins (IV).

The expression "congestive HF" is sometimes used to describe HF with evidence of fluid retention, and hepatic congestion is often present in these patients. Thus, a combination of congestive and ischemic liver injury, respectively

due to hepatic stasis and hypoperfusion, is frequently found in patients with HF [1, 5].

In this paper, we analyzed pathophysiological mechanisms that relate heart and liver in HF and examined the main liver ultrasound findings in case of HF, in particular in right heart failure (RHF).

Patophysiology of congestive hepatopathy

Elevated CVP causes the dilatation of the lobular hepatic veins and the hepatic sinusoids. Intravascular fluids pour out into the perisinusoidal space of Disse. Phenomena of local steatosic changes and atrophy occur within the centrilobular parenchyma. Fibrosis gradually progresses, forming bridges between hepatic veins, with an arrangement named ‘‘reverse lobulation”. In HF, the degree of fibrosis is positively correlated with CVP and right heart chambers dilation [5, 6].

Other changes that can be observed are local thrombotic events due to blood stasis, arterialized parenchymal perfusion because of the impaired portal inflow, hemosiderosis with red areas determining the characteristic appearance of “nutmeg liver” [7], focal nodular hyperplasia, and arterialized regenerative nodules with increased risk of developing hepatocellular carcinoma [5, 8–11].

This clinical status, named congestive hepatopathy (CH), is often asymptomatic; however, hepatomegaly and hepatojugular reflux are often detected, and mild jaundice, ascites and right upper quadrant pain can be present, especially in case of fast liver expansion. Moreover, mild hyperbilirubinemia and mildly high serum aspartate amino transferase (AST) levels can be found, especially in acute HF. Hepatic synthesis is typically preserved, but mild hypoalbuminemia may be present. Cardiac ascites shows specific characteristics as high protein content (>2.5 g/dL), serum to ascites albumin gradient ‡ 1.1, and elevated lactate dehydrogenase levels and red blood cell count [5, 12–15].

Ultrasound of congestive hepatopathy

Gray-scale findings

Echocardiography is one of the most useful tools both in cardiovascular that in liver diagnosis [16]. Grayscale ultrasonography represents the first approach to the CH imaging study. Major findings are hepatomegaly and venous enlargement involving IVC, IV, and portal vein (PV). Moreover, IVC and IV usually have a reduced or lost collapsibility during inspiration [16].

IVC diameter and collapsibility measurements are commonly used as direct signs of the patient’s fluidic status. The IVC is observed throughout the respiratory cycle, and its diameter can be assessed by using either B-mode or M-mode. Normal IVC collapsibility is >50% and it can be measured by the collapsibility index (IVC-CI), estimating the maximum diameter at the end of expiration (IVCe) and the minimum at the end of inspiration (IVCi): IVC-CI= $[(IVCe - IVCi)/IVCe] \times 100\%$ [17].

The American Society of Echocardiography [18] provides the correlation between IVC diameter and RAP: maximum size <2.1 cm and a collapse >50% during sniff correspond to a RAP of 0–5 mm Hg; maximum size >2.1 cm and a collapse >50% during sniff correspond to a RAP of 5–10 mm Hg; maximum size >2.1 and a collapse <50% during sniff correspond to a RAP of 10–20 mm Hg (Figure 1).

Several studies [19–21] provide average diameter of IV at rest and during Valsalva maneuver (Figure 2): 19.4 ± 4.0 mm at rest and 5 ± 6.6 mm with the Valsalva maneuver for intrahepatic IVC; 6.0 ± 1.5 mm and 3.8 ± 2.0 mm at rest and with the Valsalva maneuver for the middle hepatic vein; 5.6–6.2 mm at rest for the right hepatic vein, up to 8.8 mm in the presence of HF, and 13.3 mm in the presence of HF with pleural effusion.

When the liver damage advances, fibrosis, cirrhosis, and portal hypertension occur. In case of advanced fibrosis and cirrhosis, the increased parenchyma stiffness causes deformation of the veins’ profile, which become thin and serpiginous. Moreover, parenchymal edema or fibrosis can determine an abnormal liver echogenicity [5, 22].

Portal hypertension occurs when values greater than 12 mmHg in the portal vein (PV) are reached, or the pressure gradient between the PV and the hepatic veins increases more than 4–6 mm Hg. Different pathophysiological mechanisms can determine portal hypertension; however, in CH the underlying mechanism is the extrahepatic post-sinusoidal portal hypertension, due to the increased resistance downstream of the hepatic parenchyma, i.e. in the right atrium, that hinders the outflow of the IV [16].

Hepatic venous pressure gradient (HVPG) can be directly measured by interventional radiology; however, US is a non-invasive tool which allows to identify signs of portal hypertension, some of which are pathognomonic (Figure 3) [23]. In particular, by using gray-scale US it is possible to identify the following features: dilatation of PV (>13 mm) [24] and portal venous system vessels, porto-systemic collaterals and reversal of flow in the portal venous system (the

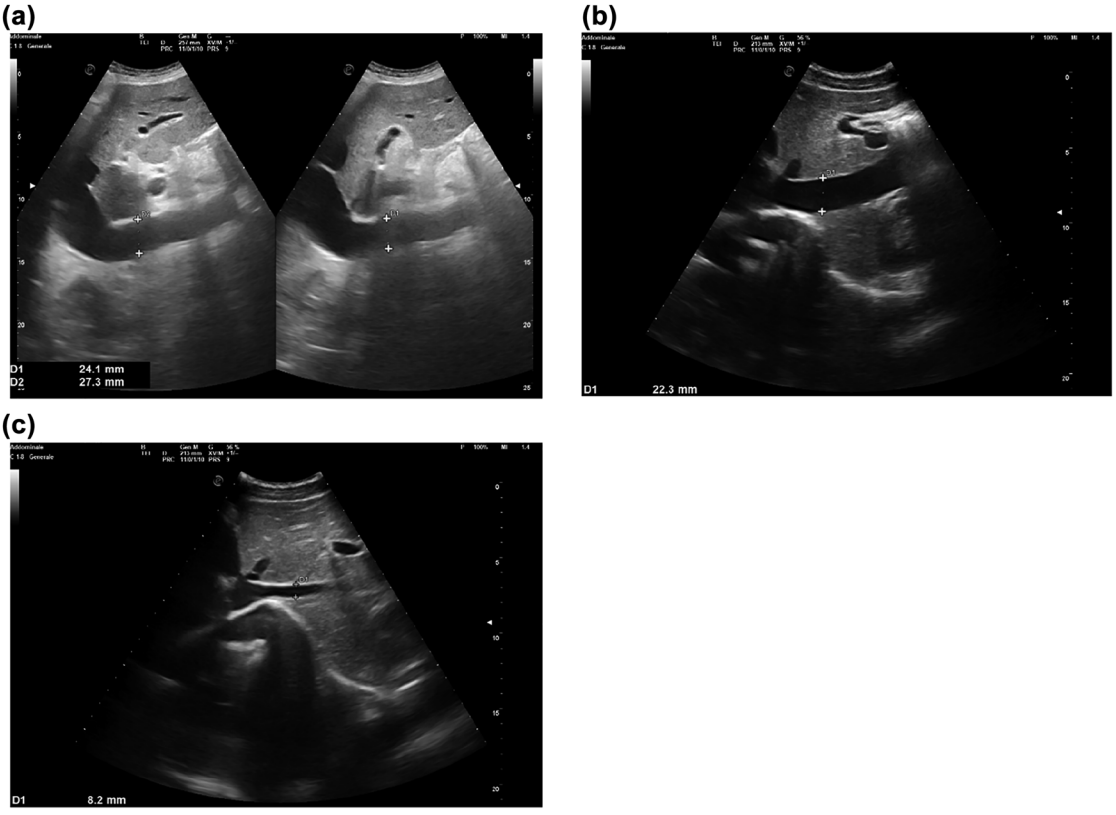

Figure 1: Inferior vena cava (IVC) imaging: reduced IVC collapsibility in patient with HF and severe volume overload (a); normal IVC collapsibility (>50%) during inspiration (b and c).

only two pathognomonic signs of portal hypertension), lack of or reduced respiratory variations of splenic and superior mesenteric vein diameter, reduced portal vein velocity, increased congestion index of the portal vein, splenomegaly, and ascites [25] (Table 1).

Ecocolordoppler and spectral velocity variations

Variations of flow characteristics involve both venous and arterial vessels.

Common findings are represented by marked phasicity of IV flow till a reverse flow, and also the PV can show increased pulsatility and phases of reverse flow and small interruptions [16].

The normal spectral Doppler pattern of IV is a triphasic wave pattern [19] made up of four waves, each one correlated with a different phase of the cardiac cycle and the right atrial activity: “a”, “S”, “v” and “D” (Figure 4a). The “a” wave is a positive wave, usually the highest above the baseline that corresponds to the end-diastolic atrial contraction, when the maximum retrograde flow occurs. The “S” wave, the first and the lowest negative wave, corresponds to the anterograde flow during ventricular systole. The “v” wave has an ascending peak, sometimes it is positive, but always below the “a” wave, and correlates with the opening of the tricuspid valve, the transition point between systole and diastole. Finally, the “D” wave is the last wave, it is negative, and it corresponds to the anterograde flow correlating with ventricular filling in the early diastole.

In HF, the increase of anterograde and retrograde speeds determines an increased pulsatility of IV flow. In tricuspid regurgitation high and both positive “a” and “v” waves are observed, with a reduced “S” wave, smaller than the “D” wave, that in severe cases can become retrograde, forming an “a-S-v complex” (Figure 4b). Also in RHF it is possible to observe high “a” and “v” waves, but with an adequate ratio between maintained S and D waves [19].

PV normally has an anterograde (hepatopetal) flow and a venous waveform resulting from cardiac activity (smoothly undulating), with systolic speeds between 16 and 40 cm/s and pulsatility index (PI, max – min/max PV flow velocity) >0.5 (Figure 5a). In HF, both tricuspid insufficiency and RHF generate an increase in pulsatility (<0.5, a lower PI indicates greater pulsatility) in the spectral curves, transmitted through the dilated sinusoids to the PV [5, 19] (Figure 5b).

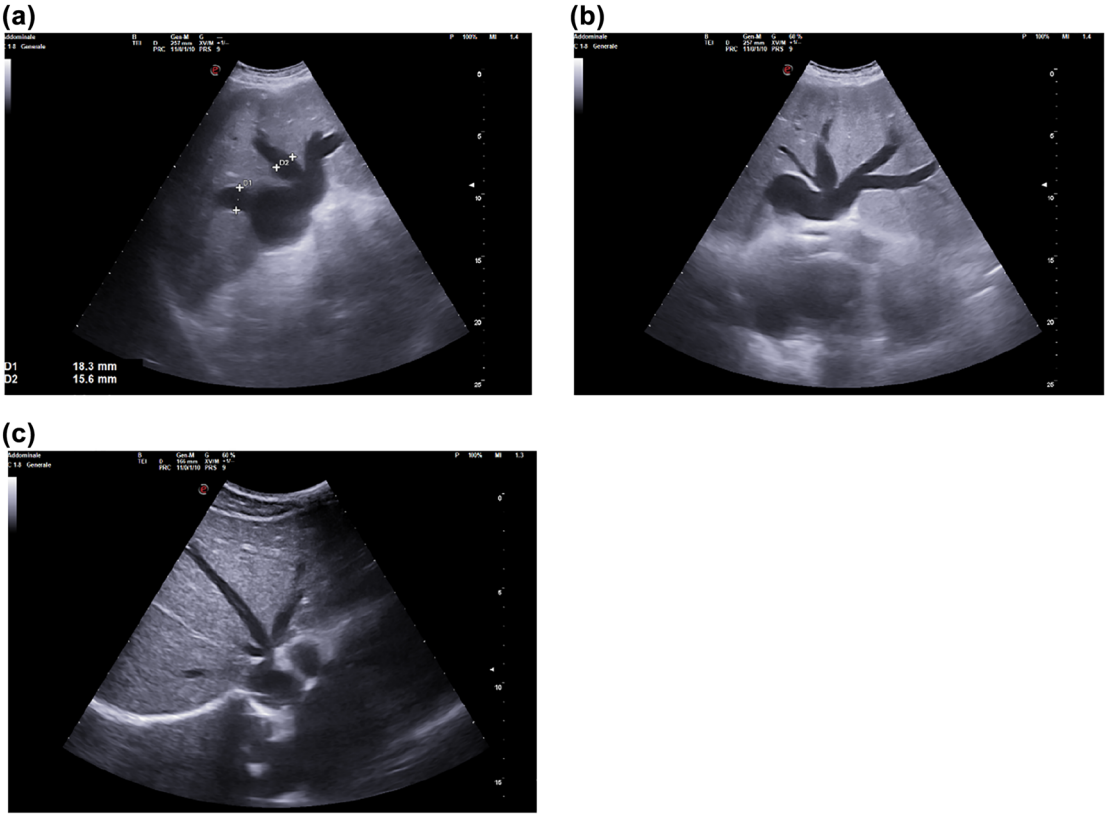

Figure 2: Dilated (a and b) and normal (c) sovrahepatic veins in patients with HF and severe volume overload.

Reduced velocity (<12.8 cm/s) in the portal trunk is a typical finding in hepatic cirrhosis, and it seems to predict decompensation in compensated cirrhosis; similarly, the reverse portal flow seems to indicate poor prognosis in decompensated cirrhosis [23].

Several studies have correlated portal flow pulsatility and HF, especially with RAP. Mostly they agree in affirming that the analysis of the PV flow can detect the elevation of RAP and allow a quantitative estimation of it, in particular with the pulsatility ratio that is inversely correlated with RAP [26, 27]. Hepatic congestion, ascites and tricuspid regurgitation seem to be associated with a higher PV pulsatility indicating that PV pulsatility ratio reflects the level of impairment of the right heart [27]. Overall results suggest that portal pulsatility ratio should be a useful reliable adjunctive sign in the evaluation process of HF, as well as in monitoring therapeutic response to volume overload reduction, even assessed by bedside US (Point-of-Care US), in both chronic and acute settings [28, 29]. On the other hand, the finding of flat PV flow wave patterns in HF patients, together with signs of congestion, can reveal an underlying primary liver disease [26].

The hepatic artery is characterized by having an anterograde flow, pulsating with low-resistance spectral waves (RI, 0.55–0.7) and maximum systolic speeds of up to 30–60 cm/s. Hepatic venous congestion causes increasing in arterial resistance (RI>0.7) as a result of diffuse vasoconstriction in acute settings, and of parenchymal fibrosis in chronic cases [19] (Figure 6). Moreover, significant correlations have been found between HVPG and intraparenchymal splenic artery resistance index, superior mesenteric artery-pulsatility index, and right interlobar renal artery resistance index [23, 30]. Anyway, all these changes in the arterial and portal flow, even if unspecific for CH, are very common in hepatic cirrhosis [19, 31].

Aforementioned spectral variations in hepatic vessels are reported in Table 2.

Elastography

Elastography is a noninvasive method to assess tissues stiffness that is the tendency to resist deformation derived from an applied force, then to resume their original shape after removal of the applied force [32]. It can be applied to the study of the organ, or the lesions present in it, and it comes from the palpatory evidence for which the pathological tissues tend to be harder. Therefore, elastography represents a virtual palpation that uses ultrasounds to understand tissues viscoelastic properties, measuring and representing

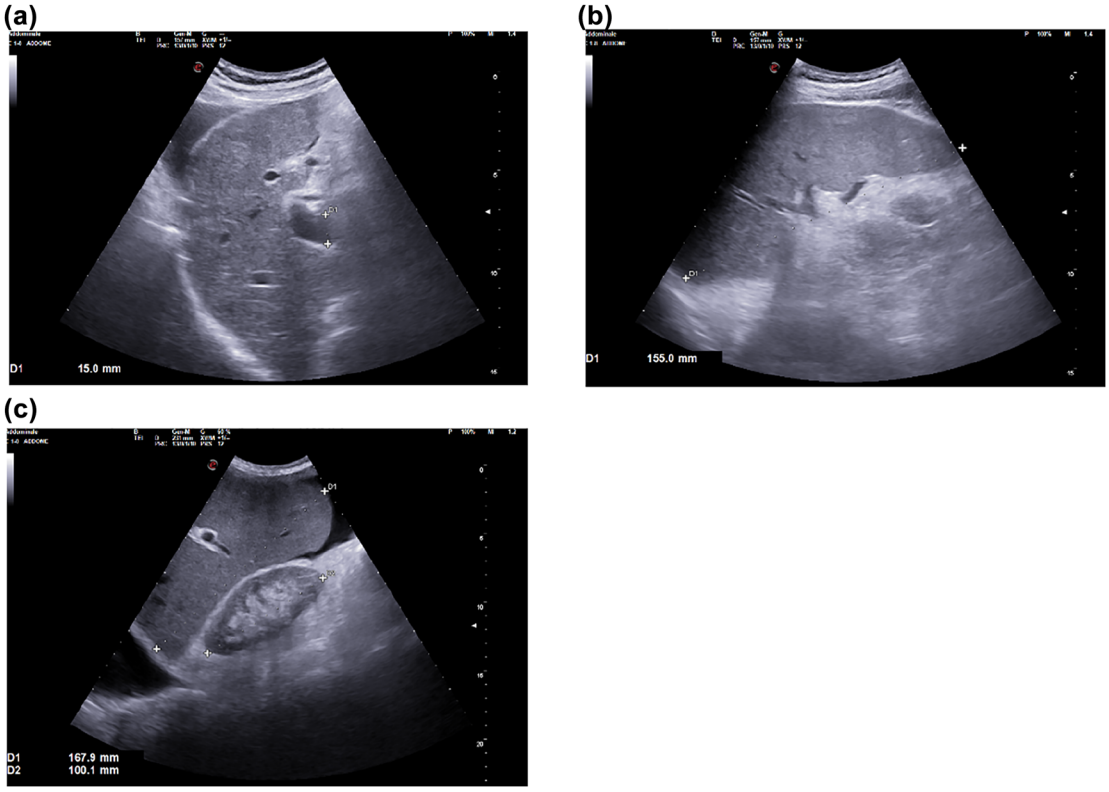

Figure 3: Ultrasound features of portal hypertension: dilated portal vein (PV) and ascites (a); splenomegaly (b); hepatomegaly with rounded angle, ascites, and pleural effusion in patient with HF and volume overload (c).

them in different ways. This is possible because compressed tissues do not change their volume, but they deform in a longitudinal or transverse direction [33, 34].

In fact the wave force can propagate to the tissue in two different ways: longitudinal wave with particle motion parallel to the direction of waves propagation, or shear wave with particle motion perpendicular to the direction of waves propagation [32].

"Strain imaging", the first ultrasound elastography technique, measures tissue displacement parallel to the applied force, using two approaches: strain elastography (SE) and acoustic radiation force (ARFI) strain. SE exploits manual compression from the operator, unable to reach deeper organs, or the internal physiologic motion of the organ (e.g. vessels pulsation, heart motion). ARFI uses an acoustic radiation force to displace tissue perpendicular to the surface. "Shear wave imaging" applies an external stress using a mechanical vibrating device (transient elastography, TE) or an acoustic radiation force (shear wave elastography, SWE), generating shear waves measured

Table 1: Main grayscale US findings.

	Hepatic veins	Portal venous system	
Normal	IVC collapsibility >50% IVC diameter ≤ 21 mm IV diameter ≤ 10 mm	PV diameter < 13 mm Preserved collapsibility	Other
Congestive hepatopathy	Increased diameter Reduced collapsibility < 50%	Increased vessels diameter (PV > 13 mm) Reduced collapsibility	Hepatomegaly Ascites Splenomegaly Porto-systemic collaterals
Liver cirrhosis	Reduced diameter Serpiginous aspect		
		Signs of portal hypertension	

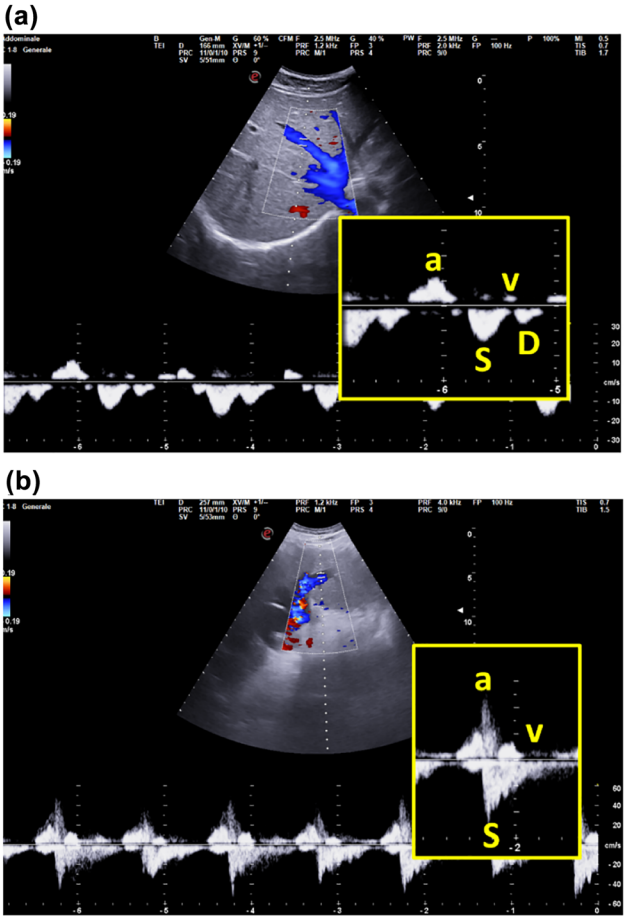

Figure 4: Spectral Doppler pattern of IV: normal triphasic wave in sovrahepatic veins (a); a-S-v complex in patient with HF and severe volume overload (b).

perpendicular to the acoustic radiation force application or parallel to the transient elastography excitation [32]. SWE includes point SWE (pSWE), two-dimensional SWE (2D-SWE) and three-dimensional SWE (3D-SWE), which differ in selected area (single focal location in pSWE or multiple focal areas in rapid succession in 2D-SWE) and in producing 2D or 3D images of the shear waves (2D-SWE vs 3D-SWE) [33].

While TE is not part of the ultrasound devices, SWE and strain characterize elastosonography, whose principle involves acquiring a real ultrasound image in B-mode, allowing to observe tissue deformation through the propagation of the US beam [34, 35]. Strain elastography obtains a box over the b-mode image providing qualitative (chromatic maps) or semi-quantitative information (relationship between the rigidity of the lesion and the adjacent parenchyma, "strain ratio") [34]. SWE not only provides a real time B-mode guide image, moreover it overcomes the limit of methods that use external stress, affected from high inter and intra operator variability due to the difficulty in reproducing the same manual compression with consequent measurements that can result very subjective, but also the internal stress, that cannot be regulated by the operator. Furthermore, SWE provides quantitative measurement of shear waves, expressed either in m/s (velocity) or kPa (stiffness), and in addition, compared to strain elastography, SWE works at deeper depth, it is more reproducible and easily becomes part of the normal US examination [32, 35].

Elastography allows to assess Liver Stiffness (LS), but, at present, without distinguishing congestion from fibrosis [5, 36]. LS is higher in patients affected by HF, when SWE considers values <5.9 kPa as normal [37]; moreover, it is even higher in patients with NYHA III/IV, with prior hospitalizations and with history of HF lasting from more than 1 year. LS decreases after HF treatment. Several works show that, in patients with HF and without chronic liver disease, LS is related to right-sided filling pressure and other parameters such as the severity of HF, NYHA class, brain natriuretic peptide (BNP), volume status, central venous pressure, liver injury, and liver function tests [36, 38–41]. Moreover, LS predicts clinical outcomes, including cardiac death and rehospitalization for HF, and it identifies patients at high risk

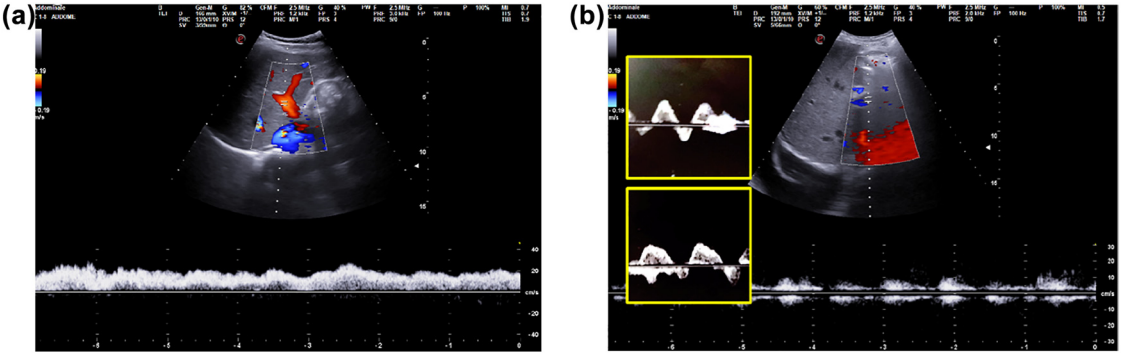

Figure 5: Portal vein (PV) flow: normal flow (5a); PV with loss of wave-form flow and different grades of increased pulsatility, besides the presence of pleural effusion (5b).

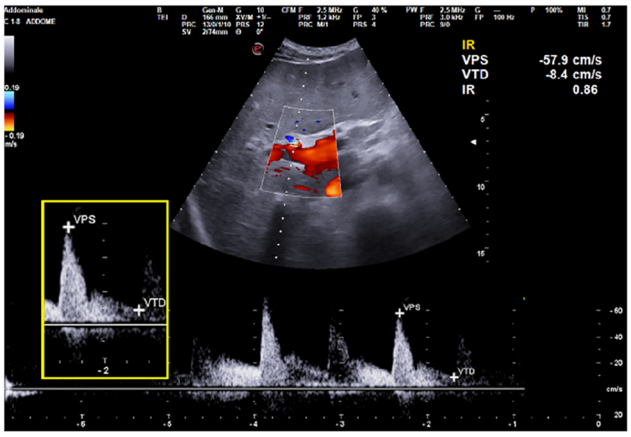

Figure 6: High resistance index in hepatic artery in a patient with multifactorial increased liver congestion.

by detecting the subclinical residual liver congestion. Its predictive value seems to have a greater diagnostic value than conventional indexes, mostly when used in conjunction [38, 42].

Contrast-enhanced ultrasound

Ultrasound contrast agents (UCA) consist of solutions of gaseous "blood pool" microbubbles, which simulate the behavior of red blood cells, and therefore increase the return signal to the probe and thus the echogenicity. UCA are rapidly dissolved in the blood and are then eliminated by the respiratory route, allowing a study lasting several minutes. First generation UCA contains air, second generation UCA contains stabilized inert gases [43].

According to other radiological contrastographic techniques, CH shows typical findings such as retrograde hepatic venous opacification during the early bolus injection and a predominantly peripheral heterogeneous pattern of hepatic enhancement due to stagnant blood flow [44]; however, contrast-enhanced ultrasound (CEUS) is not routinely used in CH assessment. CEUS, through the analysis of the interval time between vessels, regional hepatic perfusion, and relations between different vessels opacification, should allow identifying portal hypertension signs, but not pathognomic patterns for CH [23].

Table 2: Spectral variations in hepatic vessels.

	Intrahepatic veins	Portal vein	Hepatic artery
Normal	Triphasic pattern: "a" wave: positive, "a" > "v" "S" wave: negative, "S" > "D" "v" wave: positive; "v" < "a" "D" wave: negative, "D" < "S"	Anterograde flow Smoothly undulating venous waveforms Systolic speed 16–40 cm/s Pulsatility index > 0.5	Maximum systolic speed: 30–60 cm/s Resistive index 0.55–0.7
Heart failure	Increased anterograde and retrograde speeds Increased pulsatility	***All cases of hepatic congestion***	
Right heart failure	Higher "a" and "v" waves Adequate ratio maintained between S and D waves	Pulsatility index < 0.5	Resistive index > 0.7 Reduced systolic speed *(more common in LC)*
Tricuspid regurgitation	High and both positive "a" and "v" waves Reduced "S" wave "S" wave < "D" wave *Severe TR: "S" wave retrograde ("a-S-v complex")		
Liver cirrhosis	Loss of triphasic pattern	Systolic speed <12.8 cm/s till reversal flow and thrombosis	

Discussion

Liver congestion should be routinely assessed through an ultrasound exam in patients with HF regardless of pre-existing liver status. Firstly, ultrasound findings (i.e., ascites, hepatomegaly, dilation of sovrahepatic veins) can contribute to precisely defining patient's congestion status, facilitating diagnosis, stratification and, in selected cases, follow-up of therapy. On the other hand, ultrasound signs of CH may reveal changes in cardiac haemodynamic that always require cardiological evaluation. However, it should be emphasised these signs are not specific for HF and other causes of liver disease and/or congestion and high central venous pressure should be considered. Several studies explored the possible prognostic value of ultrasound and elastography evaluation in patients with HF.

A recent meta-analysis analyzed the association of LS, as assessed by transient elastography, non-alcoholic fatty liver disease fibrosis score and fibrosis-4 index, and cardiovascular outcomes in hospitalized HF patients [45]. HF is a clinical syndrome which determines not only liver congestion, but also reduced arterial flow called "hypoxic hepatopathy": decreased cardiac output causes celiac hypoperfusion. In this study abdominal ultrasonography parameters of liver hypoperfusion in patients with left-sided had prognostic impact in HF. Yoshihisa et al. demonstrated that intrahepatic congestion and hypoperfusion assessed by liver shear wave elastography and celiac peak systolic velocity correlate with adverse prognosis in patients with HF [46]. Low celiac peak systolic velocity was associated with impaired right and left systolic function (cardiac index, left ventricular ejection fraction, tricuspid valve S′, tricuspid annular plane systolic excursion) and high cardiac event rate. LS measured by two-dimensional shear wave elastography (2D-SWE) was also associated with prognosis in patients with HF with preserved ejection fraction [47], independent of standard HF risk score, serologic marker of liver disease and fibrosis, echocardiographic marker of diastolic dysfunction. The prognostic value of liver stiffness increased when combined with conventional HF risk score or NT pro-BNP measurement [48–50].

Moreover, transient elastography should be useful to assess residual congestion secondary to volume and pressure overload and/or inadequate liver perfusion in hospitalized HF patients.

According to this analysis, if further studies were carried out using a standardized method, and data remained consistent, LS should be considered a new independent prognostic marker of cardiovascular outcomes in this population, specially without concomitant liver diseases, and particularly when combined with conventional HF risk score or NTpro-BNP measurement. Moreover, LS could be used to stratify patients with HF and preserved ejection fraction (HFpEF) [51].

Conclusions

HF leads to RAP elevation and fluid retention. High volume status and right heart pressure can result in alteration of the venous and arterial hepatic circulation with consequent physiological and histological changes, leading to CH. Echography, through a morphologic and hemodynamic study of the hepatic vessels and elastography identifies characteristic signs of the congested liver. Furthermore, abdominal ultrasonography parameters of liver hypoperfusion and congestion in patients had prognostic impact in HF. Liver stiffness measured by two-dimensional shear wave elastography was also associated with prognosis in patients with HFpEF. However, ultrasound signs of congested and hypoperfused liver are not specific for HF. Thus, a multidisciplinary team is needed for diagnostic assessment and follow-up in complex patient with HF leading to CH.

Acknowledgments: The authors thank Dr. Corrado Caiazzo (Breast Service, Local Health Agency of Naples ASL NA1, Naples) for his availability and his teachings to young specialists who are passionate about ultrasound.
Research funding: The authors report no involvement in the research by the sponsor that could have influenced the outcome of this work.
Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission. Anna Lombardi, Michele Gambardella and Stefano Palermi have given substantial contributions to the conception or the design of the manuscript, all other authors to acquisition, analysis and interpretation of the data. All authors have participated to drafting the manuscript, Anna Lombardi revised it critically. All authors read and approved the final version of the manuscript.
Competing interests: Authors state no conflict of interest.
Informed consent: Not applicable.
Ethical approval: Not applicable.

References

1. McDonagh TA, Metra M, Adamo M, Gardner RS, Baumbach A, Böhm M, ESC Scientific Document Group, et al. 2021 ESC

Guidelines for the diagnosis and treatment of acute and chronic heart failure. Eur Heart J 2021;42:3599–726.
2. De Luca M, Bosso G, Valvano A, Guardasole V, Botta A, Carbone V, et al. Management of patients with chronic heart failure and type 2 diabetes mellitus: the SCODIAC-II study. Intern Emerg Med 2021;16:895–903.
3. Beigel R, Cercek B, Luo H, Siegel RJ. Noninvasive evaluation of right atrial pressure. J Am Soc Echocardiogr 2013;26:1033–42.
4. Ciozda W, Kedan I, Kehl DW, Zimmer R, Khandwalla R, Kimchi A. The efficacy of sonographic measurement of inferior vena cava diameter as an estimate of central venous pressure. Cardiovasc Ultrasound 2016;14:33.
5. Wells ML, Venkatesh SK. Congestive hepatopathy. Abdom Radiol (NY) 2018;43:2037–51.
6. Dai DF, Swanson PE, Krieger EV, Liou IW, Carithers RL, Yeh MM. Congestive hepatic fibrosis score: a novel histologic assessment of clinical severity. Mod Pathol 2014;27:1552–8.
7. Sherlock S. The liver in heart failure relation of anatomical, functional, and circulatory changes. Heart 1951;13:273–93.
8. Wells ML, Hough DM, Fidler JL, Kamath PS, Poterucha JT, Venkatesh SK. Benign nodules in post-Fontan livers can show imaging features considered diagnostic for hepatocellular carcinoma. Abdom Radiol 2017;42:2623–31.
9. Asrani SK, Warnes CA, Kamath PS. Hepatocellular carcinoma after the Fontan procedure. N Engl J Med 2013;368: 1756–7.
10. Tanaka M, Wanless IR. Pathology of the liver in Budd-Chiari syndrome: portal vein thrombosis and the histogenesis of veno-centric cirrhosis, veno-portal cirrhosis, and large regenerative nodules. Hepatology 1998;27:488–96.
11. Koehne de Gonzalez AK, Lefkowitch JH. Heart disease and the liver: pathologic evaluation. Gastroenterol Clin N Am 2017;46: 421–35.
12. Dunn GD, Hayes P, Breen KJ, Schenker S. The liver in congestive heart failure: a review. Am J Med Sci 1973;265:174–89.
13. Runyon BA. Cardiac ascites: a characterization. J Clin Gastroenterol 1988;10:410–2.
14. Fortea JI, Puente Á, Cuadrado A, Huelin P, Pellón R, González Sánchez FJ, et al. Congestive hepatopathy. Int J Mol Sci 2020;21:9420.
15. Giallourakis CC, Rosenberg PM, Friedman LS. The liver in heart failure. Clin Liver Dis 2002;6:947–67.
16. Rabbia C, Matricardi L. Eco-color-doppler vascolare, III Torino: Minerva Medica; 2006.
17. Zhao J, Wang G. Inferior vena cava collapsibility index is a valuable and non-invasive index for elevated general heart end-diastolic volume index estimation in septic shock patients. Med Sci Mon Int Med J Exp Clin Res 2016;22:3843–8.
18. Porter TR, Shillcutt SK, Adams MS, Desjardins G, Glas KE, Olson JJ, et al. Guidelines for the use of echocardiography as a monitor for therapeutic intervention in adults: a report from the American Society of Echocardiography. J Am Soc Echocardiogr 2015;28: 40–56.
19. Morales A, Hirsch M, Schneider D, González D. Congestive hepatopathy: the role of the radiologist in the diagnosis. Diagn Interv Radiol 2020;26:541–5.
20. Bang DH, Son Y, Lee YH, Yoon KH. Doppler ultrasonography measurement of hepatic hemodynamics during Valsalva maneuver: healthy volunteer study. Ultrasonography 2015;34: 32–8.
21. Henriksson L, Hedman A, Johansson R, Lindström K. Ultrasound assessment of liver veins in congestive heart failure. Acta Radiol Diagn 1982;23:361–3.
22. Scheinfeld MH, Bilali A, Koenigsberg M. Understanding the spectral Doppler waveform of the hepatic veins in health and disease. Radiographics 2009;29:2081–98.
23. Maruyama H, Yokosuka O. Ultrasonography for noninvasive assessment of portal hypertension. Gut Liver 2017;11:464–73.
24. Weinreb J, Kumari S, Phillips G, Pochaczevsky R. Portal vein measurements by real-time sonography. AJR Am J Roentgenol 1982;139:497–9.
25. Procopet B, Berzigotti A. Diagnosis of cirrhosis and portal hypertension: imaging, non-invasive markers of fibrosis and liver biopsy. Gastroenterol Rep (Oxf) 2017;5:79–89.
26. Goncalvesova E, Lesny P, Luknar M, Solik P, Varga I. Changes of portal flow in heart failure patients with liver congestion. Bratisl Lek Listy 2010;111:635–9.
27. Rengo C, Brevetti G, Sorrentino G, D'Amato T, Imparato M, Vitale DF, et al. Portal vein pulsatility ratio provides a measure of right heart function in chronic heart failure. Ultrasound Med Biol 1998;24:327–32.
28. Catalano D, Caruso G, DiFazzio S, Carpinteri G, Scalisi N, Trovato GM. Portal vein pulsatility ratio and heart failure. J Clin Ultrasound 1998;26:27–31.
29. Tremblay JA, Beaubien-Souligny W, Elmi-Sarabi M, Desjardins G, Denault AY. Point-of-Care ultrasonography to assess portal vein pulsatility and the effect of inhaled milrinone and epoprostenol in severe right ventricular failure: a report of 2 cases. A A Case Rep 2017;9:219–23.
30. Kim MY, Baik SK, Park DH, Lim DW, Kim JW, Kim HS, et al. Damping index of Doppler hepatic vein waveform to assess the severity of portal hypertension and response to propranolol in liver cirrhosis: a prospective nonrandomized study. Liver Int 2007;27: 1103–10.
31. Lemmer A, VanWagner L, Ganger D. Congestive hepatopathy: differentiating congestion from fibrosis. Clin Liver Dis 2018;10: 139–43.
32. Sigrist RMS, Liau J, Kaffas AE, Chammas MC, Willmann JK. Ultrasound elastography: review of techniques and clinical applications. Theranostics 2017;7:1303–29.
33. Bamber J, Cosgrove D, Dietrich CF, Fromageau J, Bojunga J, Calliada F, et al. EFSUMB guidelines and recommendations on the clinical use of ultrasound elastography. Part 1: basic principles and technology. Ultraschall der Med 2013;34:169–84.
34. Catalano O, Farina R. Ecografia. Dalle basi metodologiche alle tecniche avanzate. ELI - Edizioni Librarie Int 2018;63–65.
35. Sigrist RMS, Liau J, Kaffas AE, Chammas MC, Willmann JK. Ultrasound elastography: review of techniques and clinical applications. Theranostics 2017;7:1303–29.
36. Millonig G, Friedrich S, Adolf S, Fonouni H, Golriz M, Mehrabi A, et al. Liver stiffness is directly influenced by central venous pressure. J Hepatol 2010;52:206–10.
37. Fung J, Lee CK, Chan M, Seto WK, Wong DK, Lai CL, et al. Defining normal liver stiffness range in a normal healthy Chinese population without liver disease. PLoS One 2013;8: e85067.
38. Taniguchi T, Ohtani T, Kioka H, Tsukamoto Y, Onishi T, Nakamoto K, et al. Liver stiffness reflecting right-sided filling pressure can predict adverse outcomes in patients with heart failure. JACC Cardiovasc Imaging 2019;12:955–64.

39. Yoshitani T, Asakawa N, Sakakibara M, Noguchi K, Tokuda Y, Kamiya K, et al. Value of virtual touch quantification elastography for assessing liver congestion in patients with heart failure. Circ J 2016;80:1187–95.
40. Taniguchi T, Sakata Y, Ohtani T, Mizote I, Takeda Y, Asano Y, et al. Usefulness of transient elastography for noninvasive and reliable estimation of right-sided filling pressure in heart failure. Am J Cardiol 2014;113:552–8.
41. Saito Y, Kato M, Nagashima K, Monno K, Aizawa Y, Okumura Y, et al. Prognostic relevance of liver stiffness assessed by transient elastography in patients with acute decompensated heart failure. Circ J 2018;82:1822–9.
42. Soloveva AE, Kobalava ZD, Villevalde SV, Bayarsaikhan M, Garmash IV, Fudim M. [Prognostic value of liver stiffness in decompensated heart failure: results of prospective observational transient elastography-based study]. Kardiologiia 2018;S10:20–32.
43. Mulazzani L, Cantisani V, Piscaglia F. Different techniques for ultrasound liver elastography. J Hepatol 2019;70: 545–7.
44. Wells ML, Fenstad ER, Poterucha JT, Hough DM, Young PM, Araoz PA, et al. Imaging findings of congestive hepatopathy. Radiographics 2016;36:1024–37.
45. Khan MS, Siddiqi TJ, Khan SU, Shah SJ, VanWagner LB, Khan SS. Association of liver stiffness and cardiovascular outcomes in patients with heart failure: a systematic review and meta-analysis. Eur J Prev Cardiol 2020;27:331–4.
46. Yoshihisa A, Ishibashi S, Matsuda M, Yamadera Y, Ichijo Y, Sato Y, et al. Clinical implications of hepatic hemodynamic evaluation by abdominal ultrasonographic imaging in patients with heart failure. J Am Heart Assoc 2020;9:e016689.
47. Saito Y, Matsumoto N, Aizawa Y, Fukamachi D, Kitano D, Toyama K, et al. Prognostic value of liver stiffness measured by two-dimensional elastography in acute decompensated heart failure with preserved ejection fraction. Int Heart J 2021;62: 821–8.
48. De Luca M, Crisci G, Giardino F, Valente V, Amaranto I, Iacono O, et al. Anabolic hormones and heart failure with preserved ejection fraction: looking for Ariadne's thread. Monaldi Arch Chest Dis 2021: 92. https://doi.org/10.4081/monaldi.2021.1743.
49. Crisci G, De Luca M, D'Assante R, Ranieri B, D'Agostino A, Valente V, et al. Effects of exercise on heart failure with preserved ejection fraction: an updated review of literature. J Cardiovasc Dev Dis 2022;9:241.
50. Salzano A, De Luca M, Israr MZ, Crisci G, Eltayeb M, Debiec R, et al. Exercise intolerance in heart failure with preserved ejection fraction. Heart Fail Clin 2021;17:397–413.
51. Salzano A, D'Assante R, Israr MZ, Eltayeb M, D'Agostino A, Bernieh D, et al. Biomarkers in heart failure: clinical insights. Heart Fail Clin 2021;17:223–43.